

## Micro-Sensors for in-situ Meteorological Measurements

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### Abstract

Improved in-situ meteorological measurements are needed for monitoring the weather and climate of the terrestrial and martian atmospheres. We have initiated a program to assess the feasibility and utility of micro-sensors for precise in-situ meteorological measurements in these environments. Sensors are being developed for measuring pressure, temperature, wind velocity, humidity, and aerosol amounts. Silicon micro-machining and large scale integration technologies are being used to make sensors that are small, rugged, lightweight, and require very little power. Our long-term goal is to develop very accurate miniaturized sensors that can be incorporated into complete instrument packages or "micro weather stations," and deployed on a variety of platforms. If conventional commercially available silicon production techniques can be used to fabricate these sensor packages, it will eventually be possible to mass-produce them at low cost. For studies of the Earth's troposphere and stratosphere, they could be deployed on aircraft, dropsondes, radiosondes, or autonomous surface stations at remote sites. Improved sensor accuracy and reduced sensor cost are the primary challenges for these applications. For studies of the martian atmosphere, these sensor packages could be incorporated into the small entry probes and surface landers that are being planned for the Mars Environmental Survey (MESUR) Mission. That decade-long program will deploy a global network of small stations on the Martian surface for monitoring meteorological and geological processes. Low mass, low power, durability, large dynamic range and calibration stability are the principal challenges for this application. Our progress on each of these sensor types is presented below:

*a. Pressure:* The first sensor to be developed was a silicon micro-machined capacitive aneroid barometer. This sensor determines atmospheric pressure by measuring the deflection of a thin silicon membrane that separates the atmosphere from a tiny evacuated chamber. Unlike commercially available micro-machined pressure sensors, the JPL barometer uses a high-frequency capacitive circuit rather than a piezo-resistive strain gauge to measure the deflection of the membrane. This technique not only provides vast improvements in positional sensitivity and dynamic range, it also overcomes serious temperature sensitivity problems that plague existing commercial devices. Our sensors use 1 to 5 mm square membranes that are 10 to 20 micrometers thick. Their mass is less than 0.1 gram. In spite of their small size, their dynamic range exceeds 5 orders of magnitude. More testing is needed to calibrate and fully characterize these devices, but our preliminary experiments indicate that they should meet all of our requirements. Recently, the Finnish meteorological instrument company, Vaisala, has developed a similar device for use on the Mars 94/96 and MARSNET programs. We plan to obtain one or more of these devices for comparison with the JPL pressure sensor.

*b. Temperature:* A prototype thermocouple based temperature sensor for Mars applications was fabricated several years ago by J. Tillman. It produced accuracies of 0.1 °C at temperatures between -70 and 70 °C. Even though the sensor circuit uses discrete components, it requires only 0.55 Watts for continuous operation. We are currently exploring a variety of options to reduce

the size and power requirements of this design, and to improve its survivability. We are also exploring other options, including all-silicon diode sensors.

**c. Winds:** We built a small pitot-static wind sensor from commercially available micro-machined pressure sensors. It determines wind speed by comparing the pressure exerted by the wind on the face of an exposed pressure sensor (pitot pressure) to that measured by a shielded sensor (static pressure). Our prototype pitot-static anemometer could detect winds as small as 0.1 m/s at the Earth's surface, but a much more sensitive device would be needed for wind measurements at high altitudes in the Earth's atmosphere, or in the thin Martian atmosphere. The sensitivity and dynamic range of this sensor could be improved dramatically by replacing the commercial pressure sensors with the JPL or Vaisala micro-machined capacitive pressure sensors. Other measurement strategies that employ pitot-static measurements are also being studied, including the designs similar to the Orthogonal Windspeed Systems being marketed by Roscom Inc. The advantage of this sensor is that it could be built into the mast of the MARSUR landers, simplifying its deployment.

A third type of anemometer that is being considered for measuring the wind speed and direction in two dimensions is based on a mass-flow sensor. This sensor consists of a small heated element surrounded by a series of temperature sensors. The wind speed is estimated from the power needed to maintain the heated element at a constant temperature, while the wind direction is determined by comparing the temperatures measured by the surrounding temperature sensors. A silicon micro-machined 2-d mass flow sensor could be very small (0.5 sq. cm), and would consume very little power.

**d. Humidity:** Improved humidity sensors have been identified as the highest priority for both terrestrial and Martian meteorological applications. These sensors also pose the greatest technological challenges because they must provide accurate estimates of water vapor abundance for mixing ratios that vary from less than one part per million to greater than 196. We are currently testing a prototype sensor that measures humidity by determining the dew-point temperature. Dew-point sensors are intrinsically accurate because the dew-point is a well-defined thermodynamic quantity. In conventional dew-point sensors, a small mirror is cycled through temperature, and the dew-point is detected by monitoring the intensity of a light beam reflected and scattered as liquid water or ice condenses on the mirror surface. Unfortunately, these sensors are usually relatively massive, complex, and consume excessive power, and their mirrors are easily contaminated by dust and salt spray. Our prototype humidity sensor has the advantages of the chilled-mirror dew-point hygrometer, but requires a much simpler configuration, and eliminates problems with contamination of the mirror. This device is a differential microbalance (DMB), which consists of shielded and unshielded quartz crystal oscillators that are attached to an 8 mm square thermoelectric cooler (TEC). The frequencies of the two crystals are monitored as the TEC is cycled through a range of temperatures. The frequency of the unshielded crystal changes almost continuously as it adsorbs water, and then changes abruptly at the dew-point, when liquid water or ice begins to condense on its surface. Our prototype device works well, but our initial tests have revealed a few shortcomings of this design. For example, the poor thermal coupling between the crystals and the thermoelectric cooler allows substantial temperature gradients to form across the crystal faces if they are scanned too rapidly through temperature. These gradients can compromise the accuracy of the dew-point temperature measurements. We are continuing to refine the DMB sensor design to address these problems. As a first step, we are replacing the crystal oscillator with a Surface Acoustic Wave (SAW) oscillator. Unlike the crystals that are currently being used, this type of oscillator operates by setting up a surface wave, rather than a body wave in the crystal. SAW's can therefore be attached directly to the TEC to provide a much better thermal contact. This should reduce the power consumption by allowing much faster scan rates. These oscillators also operate at much higher frequencies. This should improve their sensitivity to low water vapor amounts. A second class of DMB sensor, based on silicon micromachined cantilever oscillators is also being considered.